METHOD OF CONNECTING COMPONENTS OF A MODULAR FUEL INJECTOR

Background of the Invention

It is believed that examples of known fuel injection systems use an injector to dispense a quantity of fuel that is to be combusted in an internal combustion engine. It is also believed that the quantity of fuel that is dispensed is varied in accordance with a number of engine parameters such as engine speed, engine load, engine emissions, etc.

It is believed that examples of known electronic fuel injection systems monitor at least one of the engine parameters and electrically operate the injector to dispense the fuel. It is believed that examples of known injectors use electro-magnetic coils, piezoelectric elements, or magnetostrictive materials to actuate a valve.

It is believed that examples of known valves for injectors include a closure member that is movable with respect to a seat. Fuel flow through the injector is believed to be prohibited when the closure member sealingly contacts the seat, and fuel flow through the injector is believed to be permitted when the closure member is separated from the seat.

It is believed that examples of known injectors include a spring providing a force biasing the closure member toward the seat. It is also believed that this biasing force is adjustable in order to set the dynamic properties of the closure member movement with respect to the seat.

It is further believed that examples of known injectors include a filter for separating particles from the fuel flow, and include a seal at a connection of the injector to a fuel source.

It is believed that such examples of the known injectors have a number of disadvantages.

It is believed that examples of known injectors must be assembled entirely in an environment that is substantially free of contaminants. It is also believed that examples of known injectors can only be tested after final assembly has been completed.

Summary of the Invention

According to the present invention, a fuel injector can comprise a plurality of modules, each of which can be independently assembled and tested. According to one embodiment of the present invention, the modules can comprise a fluid handling subassembly and an electrical

subassembly. These subassemblies can be subsequently assembled to provide a fuel injector according to the present invention.

The present invention provides a method of connecting a fuel group to a power group. The method includes providing a fuel tube assembly having a longitudinal axis extending therethrough; installing an orifice plate on the fuel tube assembly, rotating the power group relative to the fuel group such that the at least one opening is disposed a predetermined angle from the power connector relative to the longitudinal axis; installing the fuel group in a power group; and fixedly connecting the fuel group to the power group. The orifice plate having at least one opening disposed away from the longitudinal axis. The power group includes a generally axially extending dielectric overmold and a power connector extending generally radially therefrom.

The present invention further provides a method of connecting a fuel group to a power group in a fuel injector. The method includes manufacturing a fuel group. The manufacturing includes providing a fuel tube assembly having a longitudinal axis extending therethrough; installing an orifice plate on the fuel tube assembly, the orifice plate having at least one opening disposed away from the longitudinal axis. The method further comprises providing a power group having a generally axially extending dielectric overmold and a power connector extending generally radially therefrom; rotating the power group relative to the fuel group such that the at least one opening is disposed a predetermined angle from the power connector relative to the longitudinal axis. After the power group is rotated, installing the fuel group in the power group, and fixedly connecting the fuel group to the power group.

Brief Description of the Drawings

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate an embodiment of the invention, and, together with the general description given above and the detailed description given below, serve to explain features of the invention.

Figure 1 is a cross-sectional view of a fuel injector according to the present invention.

Figure 2 is a cross-sectional view of a fluid handling subassembly of the fuel injector shown in Figure 1.

Figure 2A is a cross-sectional view of a variation on the fluid handling subassembly of Figure 2.

Figures 2B and 2C are exploded views of the components of lift setting feature of the present invention.

Figure 3 is a cross-sectional view of an electrical subassembly of the fuel injector shown in Figure 1.

Figure 3A is a cross-sectional view of the two overmolds for the electrical subassembly of Figure 1.

Figure 3B is an exploded view of the electrical subassembly of the fuel injector of Figure 1.

Figure 4 is an isometric view that illustrates assembling the fluid handling and electrical subassemblies that are shown in Figures 2 and 3, respectively.

Figure 5 is a chart of the method of assembling the modular fuel injector of the present invention.

Detailed Description of the Preferred Embodiment

Referring to Figures 1-4, a solenoid actuated fuel injector 100 dispenses a quantity of fuel that is to be combusted in an internal combustion engine (not shown). The fuel injector 100 extends along a longitudinal axis A-A between a first injector end 238 and a second injector end 239, and includes a valve group subassembly 200 and a power group subassembly 300. The valve group subassembly 200 performs fluid handling functions, e.g., defining a fuel flow path and prohibiting fuel flow through the injector 100. The power group subassembly 300 performs electrical functions, e.g., converting electrical signals to a driving force for permitting fuel flow through the injector 100.

Referring to Figures 1 and 2, the valve group subassembly 200 comprises a tube assembly extending along the longitudinal axis A-A between a first tube assembly end 200A and a second tube assembly end 200B. The tube assembly includes at least an inlet tube, a non-magnetic shell 230, and a valve body 240. The inlet tube 210 has a first inlet tube end proximate to the first tube assembly end 200A. A second end of the inlet tube 210 is connected to a first shell end of the non-magnetic shell 230. A second shell end of the non-magnetic shell 230 is connected to a first valve body end of the valve body 240. And a second valve body end of the

valve body 240 is proximate to the second tube assembly end 200B. The inlet tube 210 can be formed by a deep drawing process or by a rolling operation. A pole piece can be integrally formed at the second inlet tube end of the inlet tube 210 or, as shown, a separate pole piece 220 can be connected to a partial inlet tube 210 and connected to the first shell end of the non-magnetic shell 230. The non-magnetic shell 230 can comprise diamagnetic stainless steel 430FR, or any other suitable material demonstrating substantially equivalent structural and magnetic properties.

A seat 250 is secured at the second end of the tube assembly. The seat 250 defines an opening centered on the fuel injector's longitudinal axis A-A and through which fuel can flow into the internal combustion engine (not shown). The seat 250 includes a sealing surface 252 surrounding the opening. The sealing surface 252, which faces the interior of the valve body 240, can be frustoconical or concave in shape, and can have a finished surface. An orifice plate 254 can be used in connection with the seat 250 to provide at least one precisely sized and oriented opening 254A in order to obtain a particular fuel spray pattern. The precisely sized opening 254A can be disposed on the axis A-A or preferably, an opening 254B disposed off-axis and orientated with respect to a fixed reference point formed on the body of the injector 100.

An armature assembly 260 is disposed in the tube assembly. The armature assembly 260 includes a first armature assembly end having a ferro-magnetic or armature portion 262 and a second armature assembly end having a sealing portion. The armature assembly 260 is disposed in the tube assembly such that the magnetic portion, or "armature," 262 confronts the pole piece 220. The sealing portion can include a closure member 264, e.g., a spherical valve element, that is moveable with respect to the seat 250 and its sealing surface 252. The closure member 264 is movable between a closed configuration, as shown in Figures 1 and 2, and an open configuration (not shown). In the closed configuration, the closure member 264 contiguously engages the sealing surface 252 to prevent fluid flow through the opening. In the open configuration, the closure member 264 is spaced from the seat 250 to permit fluid flow through the opening. The armature assembly 260 may also include a separate intermediate portion 266 connecting the ferro-magnetic or armature portion 262 to the closure member 264. The intermediate portion or armature tube 266 can be fabricated by various techniques, for example, a plate can be rolled and its seams welded or a blank can be deep-drawn to form a seamless tube. The intermediate portion

266 is preferable due to its ability to reduce magnetic flux leakage from the magnetic circuit of the fuel injector 100. This ability arises from the fact that the intermediate portion or armature tube 266 can be non-magnetic, thereby magnetically decoupling the magnetic portion or armature 262 from the ferro-magnetic closure member 264. Because the ferro-magnetic closure member is decoupled from the ferro-magnetic or armature 262, flux leakage is reduced, thereby improving the efficiency of the magnetic circuit.

Fuel flow through the armature assembly 260 can be provided by at least one axially extending through-bore 267 and at least one apertures 268 through a wall of the armature assembly 260. The apertures 268, which can be of any shape, preferably are axially elongated to facilitate the passage of gas bubbles. For example, in the case of a separate intermediate portion 266 that is formed by rolling a sheet substantially into a tube, the apertures 268 can be an axially extending slit defined between non-abutting edges of the rolled sheet. However, the apertures 268, in addition to the slit, would preferably include openings extending through the sheet. The apertures 268 provide fluid communication between the at least one through-bore 267 and the interior of the valve body. Thus, in the open configuration, fuel can be communicated from the through-bore 267, through the apertures 268 and the interior of the valve body, around the closure member, and through the opening into the engine (not shown).

At least one axially extending through-bore 267 and at least one aperture 268 through a wall of the armature assembly 260 can provide fuel flow through the armature assembly 260. The apertures 268, which can be of any shape, preferably are axially elongated to facilitate the passage of gas bubbles. For example, in the case of a separate intermediate portion 266 that is formed by rolling a sheet substantially into a tube, the apertures 268 can be an axially extending slit defined between non-abutting edges of the rolled sheet. The apertures 268 provide fluid communication between the at least one through-bore 267 and the interior of the valve body 240. Thus, in the open configuration, fuel can be communicated from the through-bore 267, through the apertures 268 and the interior of the valve body 240, around the closure member 264, and through the opening into the engine (not shown).

With reference to Figure 2B, a lift sleeve 255 is telescopically mounted in the valve body 240 to set the seat 250 at a predetermined axial distance from the inlet tube 210 or the armature in the tube assembly. This feature can be seen in the exploded view of Fig. 2B wherein the

separation distance between the seat 250and the armature can be set by inserting the lift sleeve 255 in a telescopic fashion into the valve body 240. The use of lift sleeve 255 allows the injector lift to be set and tested prior to final assembly of the injector. Furthermore, adjustment to the lift can be done by moving the lift sleeve 255 in either axial direction as opposed to scrapping the whole injector. Once the injector lift is determined to be correct, the lift sleeve 255 is affixed to the housing 330 by a laser weld.

Alternatively, a crush ring 256 can be used in lieu of a lift sleeve 255 to set the injector lift height, as shown in Fig. 2C. The use of a crush ring 256 allows for quicker injector assembly when the dimensions of the inlet tube, non-magnetic shell 230, valve body 240 and armature are fixed for a large production run.

In the case of a spherical valve element providing the closure member 264, the spherical valve element can be connected to the armature assembly 260 at a diameter that is less than the diameter of the spherical valve element. Such a connection would be on side of the spherical valve element that is opposite contiguous contact with the seat. A lower armature guide can be disposed in the tube assembly, proximate the seat, and would slidingly engage the diameter of the spherical valve element. The lower armature guide can facilitate alignment of the armature assembly 260 along the axis A-A.

A resilient member 270 is disposed in the tube assembly and biases the armature assembly 260 toward the seat. A filter assembly 282 comprising a filter 284A and an adjusting tube 280 is also disposed in the tube assembly. The filter assembly 282 includes a first end and a second end. The filter 284A is disposed at one end of the filter assembly 282 and also located proximate to the first end of the tube assembly and apart from the resilient member 270 while the adjusting tube 280 is disposed generally proximate to the second end of the tube assembly. The adjusting tube 280 engages the resilient member 270 and adjusts the biasing force of the member with respect to the tube assembly. In particular, the adjusting tube 280 provides a reaction member against which the resilient member 270 reacts in order to close the injector valve 100 when the power group subassembly 300 is de-energized. The position of the adjusting tube 280 can be retained with respect to the inlet tube 210 by an interference fit between an outer surface of the adjusting tube 280 and an inner surface of the tube assembly. Thus, the position of the adjusting tube 280 with respect to the inlet tube 210 can be used to set a predetermined dynamic

characteristic of the armature assembly 260. Alternatively, as shown in Figure 2A, a filter assembly 282' comprising adjusting tube 280A and inverted cup-shaped filtering element 284B can be utilized in place of the cone type filter assembly 282.

The valve group subassembly 200 can be assembled as follows. The non-magnetic shell 230 is connected to the inlet tube 210 and to the valve body 240. The filter assembly 282 or 282' is inserted along the axis A-A from the first inlet tube end of the inlet tube 210. Next, the resilient member 270 and the armature assembly 260 (which was previously assembled) are inserted along the axis A-A from the second valve body end of the valve body 240. The filter assembly 282 or 282' can be inserted into the inlet tube 210 to a predetermined distance so as to abut the resilient member. The position of the filter assembly 282 or 282' with respect to the inlet tube 210 can be used to adjust the dynamic properties of the resilient member, e.g., so as to ensure that the armature assembly 260 does not float or bounce during injection pulses. The seat 250 and orifice plate 254 are then inserted along the axis A-A from the second valve body end of the valve body 240. At this time, a probe can be inserted from either the inlet end 200A or the outlet end 200B to check for the lift of the injector. If the injector lift is correct, the lift sleeve 255 and the seat 250 are fixedly attached to the valve body 240. It should be noted here that both the seat 250 and the lift sleeve 255 are fixedly attached to the valve body 240 by known conventional attachment techniques, including, for example, laser welding, crimping, and friction welding or conventional welding, and preferably laser welding. The seat 250 and orifice plate 254 can be fixedly attached to one another or to the valve body 240 by known attachment techniques such as laser welding, crimping, friction welding, conventional welding, etc.

Referring to Figures 1 and 3, the power group subassembly 300 comprises an electromagnetic coil 310, at least one terminal 320 (there are two according to a preferred embodiment), a housing 330, and an overmold 340. The electromagnetic coil 310 comprises a wire that that can be wound on a bobbin 314 and electrically connected to electrical contact 322 supported on the bobbin 314. When energized, the coil generates magnetic flux that moves the armature assembly 260 toward the open configuration, thereby allowing the fuel to flow through the opening. De-energizing the electromagnetic coil 310 allows the resilient member 270 to return the armature assembly 260 to the closed configuration, thereby shutting off the fuel flow. Each electrical terminal 320 is in electrical communication via an axially extending contact

portion 324 with a respective electrical contact 322 of the coil 310. The housing 330, which provides a return path for the magnetic flux, generally comprises a ferromagnetic cylinder 332 surrounding the electromagnetic coil 310 and a flux washer 334 extending from the cylinder toward the axis A-A. The washer 334 can be integrally formed with or separately attached to the cylinder. The housing 330 can include holes and slots 330A, or other features to break-up eddy currents that can occur when the coil is energized. Additionally, the housing 330 is provided with scalloped circumferential edge 331 to provide a mounting relief for the bobbin 314. The overmold 340 maintains the relative orientation and position of the electromagnetic coil 310, the at least one electrical terminal 320, and the housing 330. The overmold 340 can also form an electrical harness connector portion 321 in which a portion of the terminals 320 are exposed. The terminals 320 and the electrical harness connector portion 321 can engage a mating connector, e.g., part of a vehicle wiring harness (not shown), to facilitate connecting the injector 100 to a supply of electrical power (not shown) for energizing the electromagnetic coil 310.

According to a preferred embodiment, the magnetic flux generated by the electromagnetic coil 310 flows in a circuit that comprises the pole piece 220, a working air gap between the pole piece 220 and the magnetic armature portion 262, a parasitic air gap between the magnetic armature portion 262 and the valve body 240, the housing 330, and the flux washer 334.

The coil group subassembly 300 can be constructed as follows. As shown in Figure 3B, a plastic bobbin 314 can be molded with the electrical contacts 322. The wire 312 for the electromagnetic coil 310 is wound around the plastic bobbin 314 and connected to the electrical contact 322. The housing 330 is then placed over the electromagnetic coil 310 and bobbin 314 unit. The bobbin 314 can be formed with at least one retaining prongs 314A which, in combination with an overmold 340, are utilized to fix the bobbin 314 to the overmold 340 once the overmold is formed. The terminals 320 are pre-bent to a proper configuration such that the pre-aligned terminals 320 are in alignment with the harness connector 321 when a polymer is poured or injected into a mold (not shown) for the electrical subassembly. The terminals 320 are then electrically connected via the axially extending portion 324 to respective electrical contacts 322. The completed bobbin 314 is then placed into the housing 330 at a proper orientation by virtue of the scalloped-edge 331. An overmold 340 is then formed to maintain the relative

assembly of the coil/bobbin unit, housing 330, and terminals 320. The overmold 340 also provides a structural case for the injector and provides predetermined electrical and thermal insulating properties. A separate collar (not shown) can be connected, e.g., by bonding, and can provide an application specific characteristic such as an orientation feature or an identification feature for the injector 100. Thus, the overmold 340 provides a universal arrangement that can be modified with the addition of a suitable collar. To reduce manufacturing and inventory costs, the coil/bobbin unit can be the same for different applications. As such, the terminals 320 and overmold 340 (or collar, if used) can be varied in size and shape to suit particular tube assembly lengths, mounting configurations, electrical connectors, etc.

Alternatively, as shown in Fig. 3A, a two-piece overmold allows for a first overmold 341 that is application specific while the second overmold 342 can be for all applications. The first overmold 341 is bonded to a second overmold 342, allowing both to act as electrical and thermal insulators for the injector. Additionally, a portion of the housing 330 can project beyond the over-mold or to allow the injector to accommodate different injector tip lengths.

As is particularly shown in Figures 1 and 4, the valve group subassembly 200 can be inserted into the coil group subassembly 300. Thus, the injector 100 is made of two modular subassemblies that can be assembled and tested separately, and then connected together to form the injector 100. The valve group subassembly 200 and the coil group subassembly 300 can be fixedly attached by adhesive, welding, or another equivalent attachment process. According to a preferred embodiment, a hole 360 through the overmold 340 exposes the housing 330 and provides access for laser welding the housing 330 to the valve body 240. The filter 284 and the retainer 283, which are an integral unit, can be connected to the first tube assembly end 200A of the tube unit. The O-rings 290 can be mounted at the respective first and second injector ends.

The first injector end 238 can be coupled to the fuel supply of an internal combustion engine (not shown). The O-ring 290 can be used to seal the first injector end 238 to the fuel supply so that fuel from a fuel rail (not shown) is supplied to the tube assembly, with the O-ring 290 making a fluid tight seal, at the connection between the injector 100 and the fuel rail (not shown).

In operation, the electromagnetic coil 310 is energized, thereby generating magnetic flux in the magnetic circuit. The magnetic flux moves armature assembly 260 (along the axis A-A,

according to a preferred embodiment) towards the integral pole piece 220, i.e., closing the working air gap. This movement of the armature assembly 260 separates the closure member 264 from the seat 250 and allows fuel to flow from the fuel rail (not shown), through the inlet tube 210, the through-bore 267, the apertures 268 and the valve body 240, between the seat 250 and the closure member 264, through the opening, and finally through the orifice disk 254 into the internal combustion engine (not shown). When the electromagnetic coil 310 is de-energized, the armature assembly 260 is moved by the bias of the resilient member 270 to contiguously engage the closure member 264 with the seat 250, and thereby prevent fuel flow through the injector 100.

Referring to Figure 5, a preferred assembly process can be as follows:

1. A pre-assembled valve body and non-magnetic sleeve is located with the valve body oriented up in a clean room.
2. A screen retainer, e.g., a lift sleeve, is loaded into the valve body/non-magnetic sleeve assembly.
3. A lower screen can be loaded into the valve body/non-magnetic sleeve assembly.
4. A pre-assembled seat and guide assembly is loaded into the valve body/non-magnetic sleeve assembly.
5. The seat/guide assembly is pressed to a desired position within the valve body/non-magnetic sleeve assembly.
6. The valve body is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the seat.
7. A first leak test is performed on the valve body/non-magnetic sleeve assembly. This test can be performed pneumatically.
8. The valve body/non-magnetic sleeve assembly is inverted so that the non-magnetic sleeve is oriented up.
9. An armature assembly is loaded into the valve body/non-magnetic sleeve assembly.
10. A pole piece is loaded into the valve body/non-magnetic sleeve assembly and pressed to a pre-lift position.

11. Dynamically, e.g., pneumatically, purge valve body/non-magnetic sleeve assembly.
12. Set lift.
13. The non-magnetic sleeve is welded, e.g., with a tack weld, to the pole piece.
14. The non-magnetic sleeve is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the pole piece.
15. Verify lift
16. A spring is loaded into the valve body/non-magnetic sleeve assembly.
17. A filter/adjusting tube is loaded into the valve body/non-magnetic sleeve assembly and pressed to a pre-cal position.
18. An inlet tube is connected to the valve body/non-magnetic sleeve assembly to generally establish the fuel group subassembly.
19. Axially press the fuel group subassembly to the desired over-all length.
20. The inlet tube is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the pole piece.
21. A second leak test is performed on the fuel group. This test can be performed pneumatically.
22. The fuel group subassembly is moved outside the clean room and inverted so that the seat is oriented up.
23. An orifice is punched and loaded on the seat.
24. The orifice is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the seat.
25. The rotational orientation of the fuel group subassembly/orifice can be established with a "look/orient/look" procedure.
26. The fuel group subassembly is inserted into the (pre-assembled) power group subassembly.
27. The power group subassembly is pressed to a desired axial position with respect to the fuel group subassembly.

28. The rotational orientation of the fuel group subassembly/orifice/power group subassembly can be verified.

29. The power group subassembly can be laser marked with information such as part number, serial number, performance data, a logo, etc.

30. Perform a high-potential electrical test.

31. The housing of the power group subassembly is tack welded to the valve body.

32. A lower O-ring can be installed. Alternatively, this lower O-ring can be installed as a post test operation.

33. An upper O-ring is installed.

34. Invert the fully assembled fuel injector.

35. Transfer the injector to a test rig.

To ensure that particulates from the manufacturing environment will not contaminate the fuel group subassembly, the process of fabricating the fuel group subassembly is preferably performed within a "clean room". "Clean room" here means that the manufacturing environment is provided with an air filtration system including a positive pressure environment that will ensure that the particulates will be removed from the clean room.

Despite the use of a clean room, however, particulates such as polymer flashing and metal burrs may still be present in the partially assembled fuel group. Such particulates, if not removed from the fuel injector, may cause the completed injector to jam open, the effects, which may include engine inefficiency or even a hydraulic lock of the engine. To prevent such a scenario, the process can utilizes at least a washing process after a first leak test and a prior to a final flush process during break-in (or burn-in) of the injector.

To set the lift, i.e., ensure the proper injector lift distance, there are at least four different techniques that can be utilized. According to a first technique, a crush ring that is inserted into the valve body 240 between the lower guide 257 and the valve body 240 can be deformed a predetermined distance due to the deformation of the crush ring. According to a second technique, the relative axial position of the valve body 240 and the non-magnetic shell 230 can be adjusted to a predetermined distance depending on the lift distance desired, before the two parts are affixed together. According to a third technique, the relative axial position of the non-

magnetic shell 230 and the pole piece 220 can be adjusted to a predetermined distance as a function of the desired injector lift, before the two parts are affixed together. And according to a fourth technique, a lift sleeve 255 can be displaced axially within the valve body 240. If the lift sleeve technique is used, the position of the lift sleeve 255 can be adjusted by moving the lift sleeve 255 axially to a predetermined distance. The lift distance can be measured with a test probe. Once the lift is correct, the lift sleeve 255 is welded to the valve body 240, e.g., by laser welding. Next, the valve body 240 is attached to the inlet tube 210 assembly by a weld, preferably a laser weld. The assembled fuel group subassembly 200 is then tested, e.g., for leakage.

As is shown in Figure 5, the lift set procedure may not be able to progress at the same rate as the other procedures. Thus, a single production line can be split into a plurality (two are shown) of parallel lift setting stations, which can thereafter be recombined back into a single production line.

The preparation of the power group sub-assembly, which can include (a) the housing 330, (b) the bobbin assembly including the terminals 320, (c) the flux washer 334, and (d) the overmold 340, can be performed separately from the fuel group subassembly.

According to a preferred embodiment, wire 312 is wound onto a pre-formed bobbin 314 with at least one electrical contact 322 molded thereon. The bobbin assembly is inserted into a pre-formed housing 330. To provide a return path for the magnetic flux between the pole piece 220 and the housing 330, flux washer 334 is mounted on the bobbin assembly. A pre-bent terminal 320 having axially extending connector portions 324 are coupled to the electrical contact portions 322 and brazed, soldered welded, or preferably resistance welded. The partially assembled power group assembly is now placed into a mold (not shown). By virtue of its pre-bent shape, the terminals 320 will be positioned in the proper orientation with the harness connector 321 when a polymer is poured or injected into the mold. Alternatively, two separate molds (not shown) can be used to form a two-piece overmold as described with respect to Figure 3A. The assembled power group subassembly 300 can be mounted on a test stand to determine the solenoid's pull force, coil resistance and the drop in voltage as the solenoid is saturated.

The inserting of the fuel group subassembly 200 into the power group subassembly 300 operation can involve setting the relative rotational orientation of the orifice plate 254 with

respect to the power group subassembly 300. Since the orifice plate 254 is hermetically welded to the fuel group 200 in process station 24 of Figure 5, the orientation can be performed by rotating the fuel group to the desired position relative to the power group 300. According to the preferred embodiments, the fuel group and the power group can be rotated such that the included angle between the reference point defined by opening(s) 254B on the orifice plate 254 and a reference point on the injector harness connector 321 is within a predetermined angle. The relative orientation can be set using robotic cameras or computerized imaging devices to look at respective predetermined reference points on the subassemblies, orientating the subassemblies and then checking with another look and so on until the subassemblies are properly orientated before the subassemblies are inserted together.

The inserting operation can be accomplished by one of two methods: "top-down" or "bottom-up." According to the former, the power group subassembly 300 is slid downward from the top of the fuel group subassembly 200, and according to the latter, the power group subassembly 300 is slid upward from the bottom of the fuel group subassembly 200. In situations where the inlet tube 210 assembly includes a flared first end, bottom-up method is required. Also in these situations, the O-ring 290 that is retained by the flared first end can be positioned around the power group subassembly 300 prior to sliding the fuel group subassembly 200 into the power group subassembly 300. After inserting the fuel group subassembly 200 into the power group subassembly 300, these two subassemblies are affixed together, e.g., by welding, such as laser welding. According to a preferred embodiment, the overmold 340 includes an opening 360 that exposes a portion of the housing 330. This opening 360 provides access for a welding implement to weld the housing 330 with respect to the valve body 240. Of course, other methods or affixing the subassemblies with respect to one another can be used. Finally, the O-ring 290 at either end of the fuel injector can be installed.

The method of assembly of the preferred embodiments, and the preferred embodiments themselves, are believed to provide manufacturing advantages and benefits. For example, because of the modular arrangement only the valve group subassembly is required to be assembled in a "clean" room environment. The power group subassembly 300 can be separately assembled outside such an environment, thereby reducing manufacturing costs. Also, the modularity of the subassemblies permits separate pre-assembly testing of the valve and the coil

assemblies. Since only those individual subassemblies that test unacceptable are discarded, as opposed to discarding fully assembled injectors, manufacturing costs are reduced. Further, the use of universal components (e.g., the coil/bobbin unit, non-magnetic shell 230, seat 250, closure member 264, filter/retainer assembly 282, etc.) enables inventory costs to be reduced and permits a "just-in-time" assembly of application specific injectors. Only those components that need to vary for a particular application, e.g., the terminal 320 and inlet tube 210 need to be separately stocked. Another advantage is that by locating the working air gap, i.e., between the armature assembly 260 and the pole piece 220, within the electromagnetic coil, the number of windings can be reduced. In addition to cost savings in the amount of wire 312 that is used, less energy is required to produce the required magnetic flux and less heat builds-up in the coil (this heat must be dissipated to ensure consistent operation of the injector). Yet another advantage is that the modular construction enables the orifice disk 254 to be attached at a later stage in the assembly process, even as the final step of the assembly process. This just-in-time assembly of the orifice disk 254 allows the selection of extended valve bodies depending on the operating requirement. Further advantages of the modular assembly include out-sourcing construction of the power group subassembly 300, which does not need to occur in a clean room environment. And even if the power group subassembly 300 is not out-sourced, the cost of providing additional clean room space is reduced.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations, and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it have the full scope defined by the language of the following claims, and equivalents thereof.